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UNDERSTANDING THE EFFECT OF DEGREE OF SATURATION ON COMPRESSIVE STRENGTH BEHAVIORS FOR RECONSTITUTED CLAYEY SOIL OF DHAKA

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ABSTRACT

Using clayey soil to fill typical earthwork is a common practice in Bangladesh. Disturbed clayey soils at site are usually subjected under precompression load to achieve desired level of compaction for stabilization. Degree of saturation (DOS) affects the compressive behavior of clayey soil to a great extent. This study aims to investigate the effect of degree of saturation on unconfined compressive strength (UCS) of reconstituted clayey soil to imitate disturbed soil behavior. To this end, disturbed clay samples were collected from three different sites in Dhaka city. The collected soil samples had a liquid limit (LL) range of 28-41 and a plastic limit (PL) range of 18-25. The soil samples were reconstituted using slurry consolidation technique simulating a common practice carried out in Bangladesh to apply precompression on the subgrade layer of a pavement. USC tests were conducted on the reconstituted clay sample with varying degree of saturation. The considered range for degree of saturation in this study was 60-100%. From the test results, it was observed that the UCS increased with the decrease of degree of saturation. The relationship between the unconfined compressive strength and degree of saturation within the specified range was in agreement with the non-linear equation $y = ae^{-bx}$. The stress-strain relationship of the clay specimen also clearly indicated that the post-peak strain softening and ductility are largely dependent on the DOS of the specimens.

Keywords: Degree of saturation, Atterberg limit, Unconfined compressive strength, Clayey Soil

INTRODUCTION

Earthwork filling for civil engineering constructions (e.g foundation,embankment etc.) is the most essential task for any project.[1].In Bangladesh,specially in Dhaka ,mostly soils are cohesive (clayey soils)[2] and so for subgrade filling activities this soil has been used widely in various projects.To attain proper bearing capacity at site,necessary mechanically compaction is done is measured to ensure the quality at site.The compressive behaviour is affected by degree of saturation to a great extent.As this filling works are done usually disturbed soil and later compacted using mechanical forces,there is a scope to study the compressive behaviour of this kinds of soil.To understand and analyze the behaviour of the disturebd soils,reconsituted clay is an excellent option.

"A reconstituted clay is one that has been thoroughly mixed at between 1 and 1.5 times the liquid limit and preferably consolidated one-dimensionally":Burland[3]. Reconstituted clay is most commonly used processed clay that has been used for engineering infrastructures for decades due to the unavailability of undisturbed clay. So far, many researchers have conducted significant experiments to investigate the engineering properties of reconstituted clay. Graham et al. conducted an extensive study to compare among various soil properties like Critical state line, compressibilities, strengths and pore water pressure of natural and remolded clay through tri-axial test[4]. W Norhaliza et al in his study on shear strength of remolded samples using three different molding methods-proctor compaction method, hand operated method and miniature mold method concluded that all three methods conform to a desired shear strength though due to easiness and comfort hand operated method is more suitable[5]. Jianjun Ma et al. proposed an equation based on numerical models and experimental results to describe the intrinsic compressibility of reconstituted clay with different initial water contents[6]. Hong, Z. S et al [7], Liu, M. D [8], Sridharan, A et al [9] have notable works focusing the compressibility of reconstituted clay . To this end most of the studies mainly focused on the methods of reconstitution and compressibility of reconstituted clay but the unconfined compressive strength is a basic soil mechanical aspect to gain a first-hand information about the soil quality. This research aims to find a substantial relationship between compressive strength and degree of saturation of reconstituted clay. Besides, the behavior of stress-strain curve with respect to DOS will also be explored.

COLLECTION OF SOIL SPECIMENS

For this research, Dhaka soil has been selected for preparing reconstituted clay. The soil samples were

collected from three different location from a depth of 1.3-2.5m. The description of soil specimens collected for this study is summarized in Table 1. As presented in Table 1, the soil samples had specific gravity of around 2.6. The liquid limit (LL) and the plastic limit of the collected specimens were within the range of 30-41 and 19-24, respectively.

Table 1

Location	Sp	LL	PL	PI	USCS
Hatirpool(A)	2.6	41	24	17	CL
Ajimpur(B)	2.59	35	23	12	CL
Polashi(C)	2.61	30	19	11	CL

Note: Sp=Specific Gravity; LL=Liquid Limit, PL=Plastic Limit ;PI=Plasticity Index

RESEARCH METHODOLOGY

The research follows three steps: a) reconstitute the soil slurry by slurry-consolidation technique, b) preparation of soil specimen for UCS testing, and c) UCS testing.

The collected clay samples were first air dried and crushed into powdered form in the laboratory for testing. Laboratory tests were carried out to determine the physical properties such as liquid limit, plastic limit, plasticity index, and specific gravity. Later, all the samples were then reconstituted using K_o consolidation technique. Fig 1 shows the schematic setup diagram for the soil reconstitution process.

Reconstitution of Soil

Soil samples were reconstituted using the slurry-consolidation technique suggested by Sheeran and Krizek (1971). The reconstitution of the soil includes two major steps: preparation of slurry and Ko consolidation. The following subsections have a brief descriptions of these steps.

Preparation of Slurry

The soil was first air dried and crushed into powdered form. Then the soil was sieved through #40 sieve in order to remove any big chunk rocks or impurities which may affect the consolidation. The samples were then mixed with a water content equal to 1.15 times of liquid limits which was found as sufficient to yield uniform and homogeneous slurry.

K_o Consolidation

The soil slurry of each soil sample was then poured into three specific cylindrical molds one having diameter of 20cm and the others 26cm. Each mold containing the soil slurry has a drainage system to drain out the pore water to facilitate the consolidation.

Fig. 1 a) Ko-Consolidation of soil b) reconstituted soil specimen c) soil sample kept inside desiccator, and d) Failure plane after testing.

Each mold has perforated base plate below and top of the mold to bolster two-way drainage. The soil slurry was confined by Geo-textiles to prevent the particle migration. Lubrication was used on the inner wall to prevent any type of friction between soil and the wall of the mold. A schematic diagram showing various parts *K_o Consolidation* of have been shown in Figure 2.

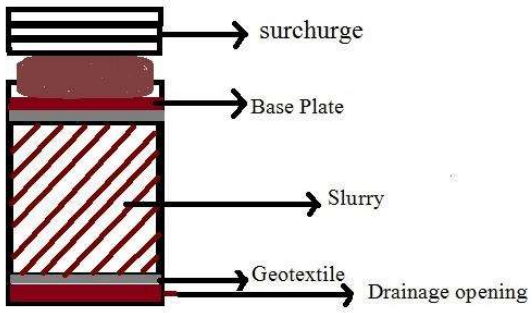

Fig. 2 Schematic diagram showing the set up for slurry- consolidation technique for sample preparation.

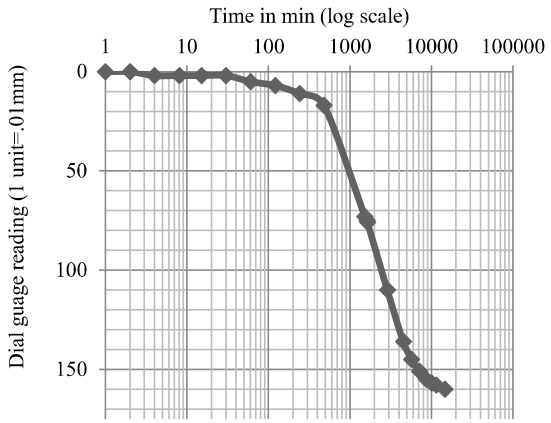

Fig. 3 A typical load-deformation curve

The prepared soil slurry was then poured inside the molds. Initially, the slurry was allowed to consolidate by the self-weight and the weight of the porous metal discs for about 48 hours. Then load was gradually applied with an increment of 50kpa. Each increment was held into position until the primary consolidation was fully completed. The time for primary consolidation was obtained from the deformation vs. time curve (Figure 3) for each incremental load. This process was repeated until pressure reached about 400kpa. It took almost 90 days for the soil samples to accomplish the primary consolidation. The time between each increment was delayed intentionally to prevent the instability of the soil structure.

Preparation of soil specimen for UCS

Once the primary consolidation was completed, the reconstituted soil sample was extracted from the mold and kept inside a desiccator for 24 hours. The soil sample was then cut and trimmed into smaller cylindrical samples for UCS test.

Determining DOS and UCS

The reconstituted soil specimen, after extracting from the mold, was kept initially in desiccator for 24 hours. Then the sample was divided into several smaller samples to facilitate the study. All the samples had height to diameter ratio greater than 2 (ASTM D2166-00). The sample was initially 100% saturated and degree of saturation decreased as the time went by and to foster the rate of decrease the lid of the desiccator was left open intentionally. For the first few samples unconfined compression test was conducted at 6 hours interval and later 24 hours. Every time after the unconfined compression test soil samples was oven dried to find the moisture content and hence degree of saturation was calculated.

To determine the unconfined compressive strength, unconfined compression test was performed in accordance to ASTM D2166 (2000). A typical stress strain curve obtained from UCS test is shown in Fig 4.

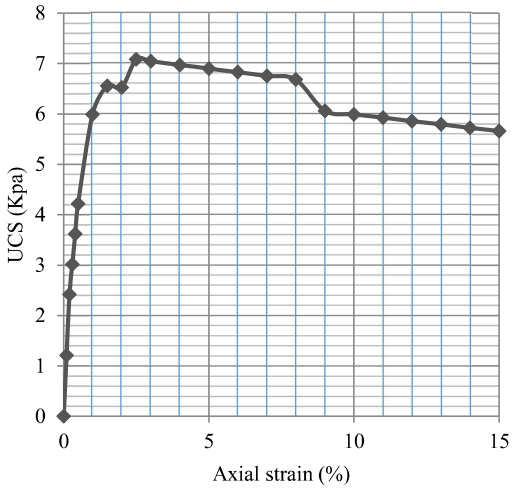

Fig. 4. A Typical stress-strain curve obtained in UCS test.

RESULTS AND ANALAYSIS

Influence of degree of saturation on UCS

Figure 5 shows the results of unconfined compressive tests under various degree of saturations for Sample A, sample B and sample C. It is apparent that the unconfined compressive strength increases with the reduction of degree of saturation for each of the sample. It is interesting to note that, for all three samples, initially the rate of increase of UCS are small. However, a drastic increase in UCS is observed once the degree of saturation drops below 90%. Therefore, care must be taken while measuring the UCS for samples having degree of saturation less than 90% since a slight decrease in degree of saturation may alter the UCS significantly. This phenomenon is more pronounced for sample B and C, where the plasticity indices were comparatively lower.

As mentioned earlier, in all three cases it was observed that initially the rate of increase is steady but when the degree of saturation is below 90% the UCS increases drastically. Based on this observation, relationships were developed between UCS and degree of saturation. The relationships for all the samples are summarized in Table 2.

As shown in Table 2, the relationship found between degree of saturation and UCS is exponential and can be expressed in the following form.

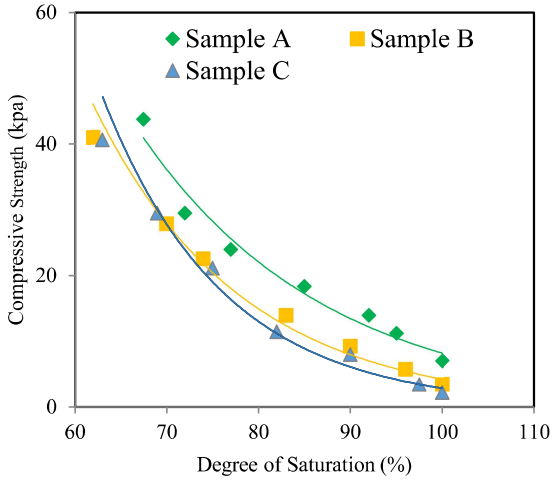

Fig. 5 Variation of UCS with respect to degree of saturation

$$UCS = ae^{-b*DOS} \quad (1)$$

Where 'a' and 'b' are the coefficient of the exponential equation. 'a' represents the shifting of the graph with respect to UCS axis and 'b' represents the rate of change of UCS with respect to DOS. It is interesting to note that the value of 'b' increases with the decrease of plasticity index. Lower plasticity index represents higher percentage of silt in clay. Therefore, the rate of increase in strength in clayey soil due variation of DOS may depend on the percentage of silt in the soil. From Table 2, it is also observed that the coefficient of regression varies between 0.95 to 0.98, indicating a very strong relationship between UCS and DOS.

Table 2

ID	PI	Relationship between UCS and DOS	Coefficient of regression (R^2)
A	17	$UCS = 4375\, e^{0.060*DOS}$	0.95
B	12	$UCS = 2188\, e^{0.062*DOS}$	0.98
C	11	$UCS = 5607\, e^{0.076*DOS}$	0.97

Shear stress-strain behavior

The stress-strain curves for all the specimens are shown in Fig 6. Each curve in the figure represents the stress vs strain curve for a particular DOS. As shown in Fig 6, the soil sample became brittle with the decrease in DOS for all three samples. In other words, the strain required to mobilize the peak shear stress dicreased with the decrease of DOS. In addtion, post-peak strain softening behavior was also observed as the DOS decreased. As indicated by Fig 6, the post

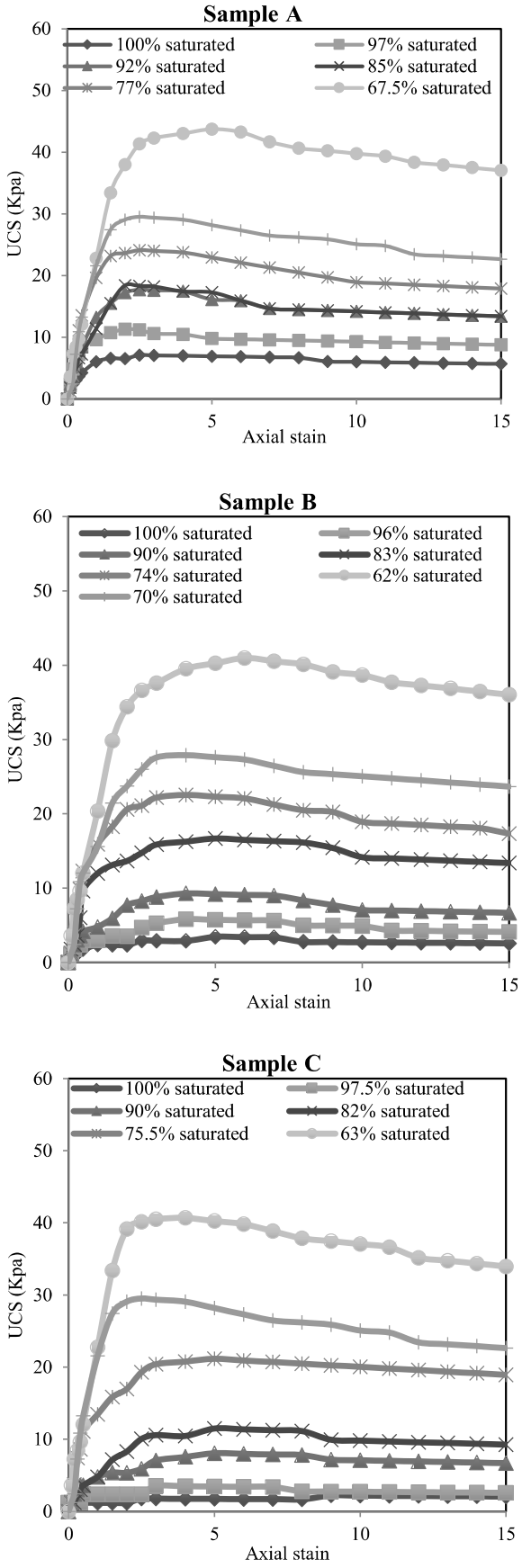

Fig. 6 Load vs strain curve for all DOS(Sample A,B,C)

peak behavior was observed once the DOS of the specimens were below 90%. However, it was more promiment when the DOS was below 80%. It is also worth mentioning that the distinct failure planes were observed of the clay samples when the DOS was below 80%, while the failure criteria observed for Specimens with higher DOS was bulging. In general, the results indicate that when the DOS of clay sample is below 90 %, it may start loosing its ductility and below 80% it may become brittle.

CONCLUSIONS

This study presented the results from the unconfined compressive strength test conducted on three different clayey soil samples with different DOS. The results of the study clearly indicated that the UCS of clay is significantly dependent on DOS and their non-linear relationship can be described with exponential equation. It was observed that the rate of increase in UCS is dependent on the PI of the clay samples. Sample with the lowest PI showed the highest rate of increase in UCS. Also, for all the soil samples, below 90% DOS, a steady increase in UCS was observed, whereas the rate of increase in UCS with the decrease of DOS was drastic for DOS below 90%. From the stress-strain curve, it was obvious that the post-peak strain softening of clayey soil is largely dependent on the DOS. The samples started showing post-peak strain softening once the DOS was below 90%. This behavior was more pronounced when DOS was lower than 80%. It was also obvious that below 80% DOS the clay soil specimens lost its ductility and behaved like a brittle material.

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